西 南 交 通 大 学

本科毕业设计（论文）外文资料翻译

城市交通网络设计问题综述

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1 引言

交通运输在于使人们能够参与人类活动，这一点非常重要。随着人口的不断增加，对交通运输的需求也在不断上升。道路上的交通越来越多，这反过来又导致了越来越多与出行相关的问题，如拥堵、空气污染、噪音污染和事故，尤其是在城市中心，人类活动的水平很高。政府需要妥善规划交通网络，并控制城市交通流动，以确保出行的便利性，同时缓解与出行相关的问题。更高的人口还会导致土地成本上升，尤其是在城市中心，因此更多的人选择居住在新城镇或郊区，这就需要新的交通基础设施来服务新城镇，或改善现有交通结构，以应对郊区人口的增长。这些规划、设计和管理问题在城市交通网络规划（UTNP）中传统上得到了处理。这个问题实际上可以包括郊区的设计问题，除了城市地区的问题，因为所涉及的方法基本相同。此外，这个问题可以涉及公共交通网络，除了道路网络，因为交通运输包括公共和私人交通。

在过去五十年中，UTNP 持续受到研究，相关出版物的数量随着时间的推移而增长，这可能是因为这个问题非常复杂，理论上有趣，实践中重要，并且跨学科。Boyce（1984）、Magnanti 和 Wong（1984）、Friesz（1985）、Migdalas（1995）、Yang 和 Bell（1998a）、Desaulniers 和 Hickman（2007）、Guihaire 和 Hao（2008），以及最近的 Keaptsopoulos 和 Karlaftis（2009）等人发表了综述。这些综述中的一些涉及一般网络设计问题，但有些则专门关注城市网络设计或城市交通网络的某一部分。例如，前五篇综述仅关注道路网络设计问题（RNDP），而最后三篇综述仅关注公共交通网络设计问题（PTNDP）。因此，这些综述中无法讨论 RNDP 与 PTNDP 之间的公式化方法和解决方案的相似性和差异性，这并不利于这两个研究领域的相互促进。此外，考虑道路和公共交通网络设计之间相互作用的问题在这些综述中被忽视。

本文试图通过结合改善交通网络的决策，提供 UTNDP 及其分类的整体视角。在这方面，当前的论文涵盖了两个问题类别，并提出了一个第三个问题类别，涉及道路和公共交通网络的联合决策，至少包含两种模式，考虑这些模式之间的相互作用。本文还包含截至 2011 年初的两个领域的最新文献。

这项贡献是指 1990 年代末发表的关于 RNDP 的最后一篇综述论文，以及涵盖到 2007 年的 PTNDP 的前几篇综述。本文的主要目的是涵盖与城市交通网络拓扑

及其配置相关的问题。在这方面，本文仅涵盖战略层面和与网络拓扑相关的一些战术层面决策；与网络拓扑决策无关的论文，例如与运营层面决策和与网络拓扑无关的战术决策，将不被涵盖，除非它们与网络拓扑决策一起考虑。诸如交通信号设置、停车定价、收费设置和公共交通票价等问题是 UTNDP 的重要子问题，其中一些有着悠久的历史，具有许多重要特征和发展。这些子问题值得在未来的综述论文中以全面的方式进行研究和审查，因此在本文中被排除。交通信号设置与网络配置决策的相关性最强，因为网络拓扑直接影响流量模式和交叉口的冲突点。这个子问题已经得到了广泛研究，并且有相对较大的文献基础(例如,Cantarella 等，1991；Meneguzzer，1995；Wong 和 Yang，1999；Wey，2000；Cascetta 等，2006）。

此外，这篇综述专注于确定性交通网络和确定性出行需求。也就是说，我们关注假设没有供需不确定性的论文。例如，所审查的论文中没有考虑出行需求和道路容量的随机性。尽管如此，我们仍然可以识别当前的趋势和差距，如后文所示，并在最后一节中强调这一领域的新研究方向。

除了回顾 UTNDP 外，我们还回顾了解决方案方法。这使得能够比较 UTNDP 不同类别中不同问题的解决方案方法，并提出新的算法研究方向。考虑到这些方法是解决实际设计问题所需的，而它们的问题规模越来越大，这一算法综述和新方向尤为重要。真实案例研究也被审查，以提供关于当前考虑的每个问题目录的网络规模的见解，并为实际问题的解决方案方法的未来需求提供一些线索。

本文的其余部分组织如下：第 2 节解释 UTNDP 的关键定义、分类和一般公式；第 3 节回顾文献中研究的具体问题；第 4 节描述文献中使用的解决方案方法；第 5 节描述对真实案例场景的应用；第 6 节展示 UTNDP 研究发展的总体视图。最后，第 7 节总结并提出进一步的研究方向。

2 UTNDP 的定义、一般公式和分类

2.1. UTNDP 的定义

文献中至少有三种不同的 UTNDP 定义：

1. UTNDP 涉及新街道的建设或现有街道容量的扩展（Dantzig 等，1979）。这个定义在文献中相当常见，但大多数研究使用其他名称来描述这个问题目录，如道路网络设计问题（RNDP）、交通网络设计问题和网络设计问题。

2. UTNDP 旨在确定要添加到交通网络中的设施的最佳位置，或确定网络中现有设施的最佳容量提升（Friesz，1985）。在这个定义中，设施可以用节点或链接表示。因此，这个定义比第一个更广泛。

3. UTNDP 涉及交通规划中决策过程的完整层次，包括战略、战术和操作决策（Magnanti 和 Wong，1984）。战略决策是与交通网络基础设施相关的长期决策，包括公共交通和道路网络；战术决策涉及对现有城市交通网络基础设施和资源的有效利用；而操作决策是短期决策，主要与交通流控制、需求管理或调度问题相关。图 1 给出了 UTNP 中战略、战术和操作决策的示例：阴影部分与网络拓扑相关。这个定义在三者中范围最广，因为它除了涵盖战略层面的规划外，还包括战术和操作层面的管理方面。

为了在一个统一的框架下创建一个全面和综合的分类集合，本文采用了 UTNDP 的第三种定义，但主要限于第二种定义中指定的决策——与网络拓扑相关的决策。实际上，我们认为这个定义涵盖了道路网络设计问题（RNDP）和公共交通网络设计与调度问题（PTINSDP），在后文中将省略“公共”一词，以便简洁，因为交通网络既包括公共交通网络，也包括道路网络。此外，我们认为这个定义包括 UTNDP 的两个大类：（1）通过添加链接开发新网络的问题，这与战略决策相关；（2）改善或管理当前网络的问题，这与战术和操作决策相关。

2.2. UTNDP 的一般框架

UTNDP 与其他学科（如电信）中的网络设计问题不同，因为在设计交通网络时必须考虑旅行者的反应。此外，设计网络还与特定的交通政策相关。基于这两个事实，对 UTNDP 的分析和建模涉及两个问题：(1)网络改善的政策制定和(2)预测网络用户在响应制定的设计政策时的行为。本节的其余部分将从上述两个方面讨论该问题。

2.2.1. UTNDP 的一般数学模型

该问题通常被表述为一个双层问题或领导者-追随者问题。上层问题是领导者的问题，即设计问题或决策者（例如政府）规划或管理交通网络的问题。这个上层问题与实践中的政策讨论相关，包含可度量的目标(例如，减少总旅行时间)、限制条件（例如，政治、物理和环境约束）以及需要做出的设计决策（例如，建设新道路）。这个上层问题假设决策者了解旅行者的行为。下层问题是旅行者的

问题，或旅行者对决策者的决策及其出行方式和路线的反应。这个下层结构使决策者能够考虑旅行者的反应，并改善网络以影响旅行者的出行选择，但对他们的行为没有直接控制。决策者不允许旅行者自由选择路线，而是允许他们在知晓领导者的决策后再做出选择。

使用精确解法解决双层网络设计问题非常困难，因为该问题是 NP 难的。Ben-Ayed 等人（1988）研究了双层问题，并得出结论，即使是一个简单的双层问题，若上层和下层问题均为线性问题，仍然是 NP 难的。另一个原因是双层网络设计问题的非凸性。即使上层和下层问题都可能是凸的，但双层问题的凸性无法得到保证（Luo 等，1996）。

所呈现的数学模型主要对应于 RNDP，而由于 TNDPS 的复杂性，只有在某些情况下才能将 TNDSP 表述为双层网络设计问题。大多数 TNDPS 是单层问题，其中用户的反应被简化。正如 Chakroborty（2003）所提到的，将 TNDSP 表述为数学问题是困难的，因为它本质上是离散的，并且像换乘和路线连续性这样的概念很难表示。最后，Baaj 和 Mahmassani（1991）讨论了该问题的复杂性，源于其组合性、非线性、非凸性和多目标特性。他们还描述了将其表述为数学模型的困难，以及定义可接受的空间路线布局的挑战。

R Z Farahani, E Miandoabchi, W Y Szeto, H Rashidi. A review of urban transportation network design problems[J]. European journal of operational research, 2013, 229(2): 281-302.

1. Introduction

Transportation is important in the sense that it allows people to take part in human activities. With an increasing population, the demand for transportation is also increasing. More and more traffic is on roads, which in turn creates more and more mobility-related problems such as congestion, air pollution, noise pollution, and accidents; especially in city centers where the level of human activities is high. Governments need to plan transport networks properly and control urban traffic movements to ensure mobility and mitigate mobility-related problems simultaneously. A higher population also leads to more expensive land, especially in city centers and hence more people living in new towns or suburbs, thereby requiring new transportation infrastructures for serving new towns or improving existing transportation structures to cope with the increasing population in the suburbs. These planning, design and management issues are traditionally addressed in UTNP. This problem can actually include the design problems in suburban areas in addition to those in urban areas, because the methodology involved is basically the same. Moreover, this problem can involve transit networks in addition to road networks, since transportation includes both public and private transport.

UTNP has been continuously studied during the last five decades, and the number of related publications has grown over time, probably because the problem is highly complicated, theoretically interesting, practically important, and multidisciplinary. Reviews have been published by Boyce (1984), Magnanti and Wong (1984), Friesz (1985), Migdalas (1995), Yang and Bell (1998a), Desaulniers and Hickman (2007), Guihaire and Hao (2008), and recently by Keaptsopoulos and Karlaftis (2009). Some of these reviews deal with general network design problems, but some focus specifically on urban network design or on one part of urban transportation networks. For example, the first five reviews only focus on RNDP, while the last three reviews only focus on PTNDP. As a result, the similarities and differences of the formulation approaches and solution methods between RNDP and PTNDP cannot be addressed in these reviews, and this does not encourage the cross-fertilization of the two research areas. Moreover, the problem that considers the interaction between road and public transit network designs has been ignored in these reviews.

This paper attempts to provide a holistic view of UTNDP and its classifications by uniting the decisions for improving transportation networks. With regard to this, the current paper covers both problem categories, and presents a third problem category for the joint decisions in road and public transit networks with at least two modes, which considers the interactions of these modes. This paper also contains updated literature for both fields to early 2011.

This contribution refers to the last review paper on RNDP which was published in the late 1990s, and the previous reviews of PTNDP which cover the literature until 2007. The main aim of this paper is to cover problems related to urban transportation network topology and its configuration. In this regard, only the strategic level and a number of tactical level decisions related to network topology are covered in this paper; those papers not related to network topology decisions, such as operational levels decisions and tactical decisions that are not related to network topology, will not be covered unless they are considered together with network topology decisions. Problems such as traffic signal setting, parking pricing, toll setting, and public transit ticket pricing are important sub-problems of UTNDP and even some of these have a long history with many important features and developments. These sub-problems deserve to be examined and reviewed in a comprehensive manner in future review papers and hence are excluded from this paper. Traffic signal setting has the strongest relevancy with network configuration decisions, as the network topology directly affects the flow pattern and the conflict points at intersections. This sub-problem has been studied extensively and there is a relatively large body of literature (e.g. Cantarella et al., 1991; Meneguzzer, 1995; Wong and Yang, 1999; Wey, 2000; Cascetta et al., 2006).

Moreover, this review focuses on deterministic transport networks and deterministic travel demand. That is, we focus on papers that assume no supply and demand uncertainty. For example, there is no randomness in travel demand and road capacity considered in the reviewed papers. Nevertheless, we can still identify current trends and gaps as shown later, and highlight new research directions in this field as shown in the last section.

Other than reviewing UTNDP, we also review the solution methods. This allows comparisons of solution methods of different problems in various classes of UTNDP and proposes new algorithmic research directions. This algorithmic review and the new directions are particularly important, given that these methods are required to solve practical design problems, and their problem sizes have become larger and larger. Real case studies are also reviewed to give insight about the size of the networks for each problem catalogue currently considered and give some hints on the future requirement of the solution methods for practical problems.

The rest of the paper is organized as follows: Section 2 explains the key definitions, classifications, and general formulations of UTNDP; Section 3 reviews the specific problem studied in the literature; Section 4 depicts the solution methods used in the literature; Section 5 describes the application to real case scenarios; and Section presents an overall view of the research development of UTNDP. Finally, the summary and further research directions are presented in Section 7.

2. Definitions, general formulations and classifications of UTNDP

2.1. Definitions of UTNDP

There are at least three different definitions of UTNDP in the literature:

1. UTNDP is concerned with building new streets or expanding the capacity of existing streets (Dantzig et al., 1979). This definition is quite common in the literature, but most studies use other names for this problem catalogue such as the Road Network Design Problem (RNDP), the transportation network design problem, and the network design problem.
2. UTNDP is to determine the optimal locations of facilities to be added into a transportation network, or to determine the optimal capacity enhancements of existing facilities in a network (Friesz, 1985). In this definition, the facilities may be represented by either nodes or links. Therefore, this definition is wider than the first one.
3. UTNDP deals with a complete hierarchy of decision-making processes in transportation planning, and includes strategic, tactical and operational decisions (Magnanti and Wong, 1984). Strategic decisions are long-term decisions related to the infrastructures of transportation networks, including both transit and road networks; tactical decisions are those concerned with the effective utilization of infrastructures and resources of existing urban transportation networks; and operational decisions are short-term decisions, which are mostly related to traffic flow control, demand management or scheduling problems. Fig. 1 gives examples of strategic, tactical and operational decisions in UTNP: the shaded items are related to network topology. This definition has the widest scope among the three, since it includes the

management aspect at the tactical and operational levels in addition to the planning aspect at the strategic level.

In order to create a comprehensive and integrated collection of classifications under a single umbrella, this paper adopts the third definition of UTNDP, but mainly limits itself to the decisions specified in the second definition – the decision related to network topology. Actually, we believe that this definition encompasses both the Road Network Design Problem (RNDP) and the Public Transit Network Design and Scheduling Problem (PTINSDP) in which the term ‘public’ will be omitted in the rest of paper for the sake of brevity, that determines the optimal transit routes, frequencies, and time-tables, because transport networks include both transit and road networks. In addition, we believe that this definition includes two big classes of UTNDP: (1) the problem of developing a new network via adding links, which is related to strategic decisions and (2) the problem of improving or managing the current network, which is related to the tactical and operational decisions.

2.2. General framework of UTNDP

UTNDP differs from network design problems in other disciplines such as telecommunication, because the reaction of travelers has to be taken into account when designing a transportation network. Moreover, designing a network is associated with certain transport policy. Regarding these two facts, analyzing and modeling in UTNDP involves two issues: (1) policy-making for network improvement and (2) predicting the network user behaviors in response to the formulated design policies. The rest of this section will discuss the problem from the mentioned aspects.

2.2.1. General mathematical model for UTNDP

The problem is usually formulated as a bi-level problem or a leader-follower problem. The upper level problem is the leader’s problem, the design problem, or the problem of the decision-maker, (e.g. the government), who plans or manages the transport network. This upper-level problem is related to the policy discussion in practice and includes the measurable goal (e.g., reducing total travel time), restrictions (e.g. political, physical, and environmental constraints) and the design decisions to be made (e.g. new roads to be built). This upper-level problem assumes that the decision-maker knows the behavior of the travelers. The lower-level problem is the travelers’ problem or the problem of travelers who react to the decisions of the decision-maker, or their travel modes and routes. This lower-level structure allows the decision-maker to consider the reaction of the travelers and improve the network to influence the travel choices of the travelers but has no direct control on their behavior. The decision-maker does not allow the travelers to determine their routes freely, but rather allows them to determine their choice after knowing the decision of the leader.

Solving a bi-level network design problem using exact solution methods is very difficult because the problem is NP-hard. Ben-Ayed et al. (1988) studied bi-level problems and concluded that even a simple bi-level problem with both linear upper-level and lower-level problems is also NP-hard. Another reason is the non-convexity of bi-level network design problems. Even if both the upper and lower level problems may be convex, the convexity of the bi-level problem cannot be guaranteed (Luo et al., 1996).

The presented mathematical model mostly corresponds to RNDPs, while due to the complexity of TNDPS only in some cases is formulating the TNDSP as a bi-level network design problem possible. Most of the TNDPS are single level problems where the reactions of users are simplified. As mentioned by Chakroborty (2003), it is difficult to formulate a TNDSP as a mathematical problem, since it is inherently discrete and concepts such as transfers and route continuity are hard to represent. Finally, Baaj and Mahmassani (1991) discussed the complexity of this problem arising from its combinatorial, non-linearity, non-convexity and multi-objective nature. They also depicted the difficulties in formulating as a mathematical model, and in defining acceptable spatial route layouts.